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SOLAR EFFECTS ON VHF COMMUNICATIONS BETWEEN A SYNCHRONOUS SATELLITE RELAY AND EARTH GROUND STATIONS

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ABSTRACT

Solar effects on VHF communication links utilizing a synchronous satellite relay were investigated. The study was conducted from January to August 1967 as part of the Weather Facsimile experiment. Observed interference effects are discussed in relation to sunspot number, solar flares and ionospheric disturbances, solar radio emissions, geomagnetic activity, and magnetic storms.

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INTRODUCTION

An investigation has been performed to correlate VHF interference, as reported by participating ground stations, with the occurrence of certain solar phenomena. The participating ground stations were taking part in the Weather Facsimile (WEFAX) experiment, which utilizes the Applications Technology Satellite (ATS)-1 to relay processed meteorological data from a central weather station to the ground stations. The VHF communication system, located on board the satellite, is an active frequency translator with an uplink receive frequency of 149.22 MHz and a downlink transmit frequency of 135.6 MHz. The data were transmitted to the satellite from the ATS ground station located at Mojave, California. The ATS-1 satellite is at an altitude of 19,300 nautical miles and is located over the equator at 151° West longitude. Approximately 50 ground stations located in an area extending from the east coast of the United States to Australia and Japan participated in the program. The analysis was conducted over an 8-month period beginning on January 2, 1967 and continuing through August of the same year.

BACKGROUND INFORMATION

While much is known concerning the effects of solar interference on ground-to-ground communications, virtually no work has been done in the area of transionospheric communications. A review of solar effects on ground-to-ground communications can, however, provide some clues as to which solar phenomena might adversely affect satellite transmissions.

It would be beyond the scope of this paper to present the various current theories of what sunspots actually are, or to discuss how solar flares might be formed. Rather, we shall simply accept their existence and confine our attention to the ways in which these and other solar phenomena affect terrestrial communications.

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The ionosphere consists of at least four concentric layers of ionized air extending from a height of about 80 to 350 km. The ionization in these layers is caused primarily by ultraviolet radiation from the sun and increases from layer to layer with height. It is the ability of these ionized layers to "reflect" (actually refract) radio waves that makes long-range (beyond line-of-sight) radio communications possible. As the electron density in the higher layers increases, radio waves of higher and higher frequency are reflected. The "critical penetration frequency" is proportional to the square root of the electron density. The lowest (D) layer with an electron density of about 10^3 electrons/cm³ reflects radio waves with frequencies of 50 kHz or less while the highest (F₂) layer with an electron density of about 10^6 electrons/cm³ ordinarily reflects frequencies of 10 MHz or less.

The electron densities in the layers of the ionosphere strongly depend on solar activity. During the 11-year sunspot cycle, for example, the electron density may vary by as much as a factor of two in the F₂-layer from sunspot minimum to sunspot maximum. Solar flares, in turn, are more likely to occur with a greater number of sunspots. The immediate effect of a solar flare is to produce a flash of ultraviolet light whose intensity may be 5 to 10 times greater than that ordinarily received at the earth. The number of free electrons in the D-layer increases rapidly, bringing about sudden ionospheric disturbances, the most significant of which for our purposes is the short-wave radio fadeout. The fadeouts are caused by the increased absorption of the short waves as they pass through the D-layer. The fadeout begins suddenly during the flash of the flare and lasts for about 25 minutes, after which radio signals slowly recover their original strength. Most of the remaining varieties of sudden ionospheric disturbances affect only the very low frequencies.

Besides the immediate effects of solar flares there are delayed effects. Charged particles emitted by the sun during the flare bombard the earth's magnetism causing magnetic storms, auroral displays, and, in general, an increase in the level of geomagnetic activity. (It should be noted that not every flare produces magnetic storms, nor does every magnetic storm have its origin in the sun.)

Solar radio emission may be of several varieties. There is the background radiation of the "quiet" sun, the enhanced radiation associated with large sunspots, short bursts lasting a few seconds, and outbursts of great intensity usually associated with solar flares. These outbursts last about 10 minutes and are believed to be generated as the charged particles emitted during a flare traverse to corona. An average frequency for these flare-related outbursts is about 60 MHz; they reach the earth about 10 minutes after the "flash" is sighted. The delay between the flash and arrival of the solar radio waves decreases with increasing frequency, so that solar radio waves at about 135.6 MHz (the transmitting frequency of the WEFAX experiment) arrive after slightly less than 3 minutes.

SELECTION OF SOLAR PHENOMENA

On the basis of the effects of the various solar disturbances upon ground-to-ground communications as discussed in the previous section, a total of four solar or solar-related physical

phenomena have been selected for correlation with the occurrence of interference in the WEFAX transmissions. These are: sunspot number, solar flares, solar radio emission, and geomagnetic activity. Two other phenomena—sudden ionospheric disturbances and magnetic storms—were initially considered for separate analysis, but are so intimately associated with solar flares and geomagnetic activity, respectively, that it would have been impossible to distinguish between them. As was seen in the previous section, the short-wave radio fadeouts begin within minutes of the sighting of a flare, while magnetic storms may be most easily noted through a sharp increase in the general level of geomagnetic activity.

Two of the remaining phenomena are short-term, lasting from about a minute to a very few hours. Thus, interference caused by solar flares and solar radio emissions had to be sought through their effect on specific transmissions. Sunspot number and geomagnetic activity are more indices of the level of solar activity over prolonged periods, and thus lend themselves more readily to a statistical approach.

DATA SOURCES AND THEIR VALIDITY

Interference Data

Data on the occurrence of interference were compiled directly from the WEFAX Daily Evaluation Reports sent to Goddard Space Flight Center by the participating stations. For dealing with the short-term solar phenomena, the results of individual transmissions were recorded separately on those days when multiple transmissions occurred. One problem, particularly in February and March when numerous multiple transmissions occurred, was that the time of interference was often not given, or words such as "sporadic" or "occasional" were used. Where feasible, it was generally assumed that the main WEFAX transmission of the day was meant, or that the time slot usually monitored by a particular station was intended. To facilitate a statistical approach to the correlation with more long-range solar phenomena, the data were converted to a form indicating the percentage of stations reporting interference on a given day. First, however, those stations reporting interference caused by local sources on a given day were eliminated from the calculations. This was necessary because of the impossibility of determining whether any real non-local interference could have been observed over and above that caused by local troubles.

The reporting of interference is at least partly subjective—witness the fact that some stations almost never reported interference (regardless of the difficulties being encountered by all others), while others always did. Dramatic changes in the amount of interference occurred with shift changes at a given station, as different personnel manned the read-outs. In working with the data, considerable effort was made to compensate, partly at least, for this class of discrepancy. This, of course, amounts to a subjective interpretation of reports already subjective, but seemed justified.

Apart from monthly collections of special data, the number of stations free of local interference reporting on a single day was generally between 5 and 10. In such cases a change in one or two stations can drastically affect the interference percentages. In compilations for the long-range

solar phenomena, an interference percentage was weighted by the number of reports in its makeup, and all cases with less than five reports were dropped.

Solar Data

The solar data were obtained from the monthly publication "Solar Geophysical Data," issued by the Institute for Telecommunication Sciences and Aeronomy of the Environmental Sciences Services Administration (ESSA). The input for this publication is derived from many observatories, laboratories, and agencies throughout the world. Except for January, February, and March, the solar flare data used in this study are based on the "preliminary" listings in solar-geophysical data. The 6-month definitive up-dates of the solar flare data for the remaining months were not yet available at the time this report was published.

CORRELATION OF SOLAR PHENOMENA WITH OBSERVED INTERFERENCE

Sunspot Number

Definition

The relative sunspot number, R , is expressed by:

$$R = k(10g + s)$$

where g is the number of disturbed regions (groups and isolated spots) and s is the total number of spots, grouped or not. The constant k has a value depending upon the instrument used at a particular observatory. At Zurich, where results from other observatories are collected and examined and a final sunspot number is compiled daily, the value of k is 1.

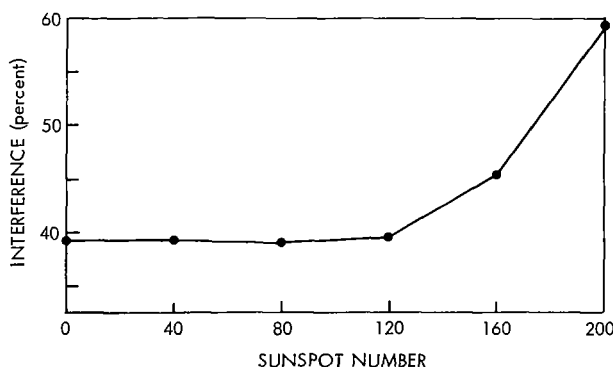


Figure 1—Interference vs sunspot number.

Findings

As has been seen, the sunspot number is more or less an index of general solar activity, and as such would not directly affect space-earth communications. Inasmuch as solar flares and radio emission are related to the sunspot number, however, communication difficulties should increase with increasing sunspot number.

Figure 1 shows the occurrence of interference expressed in percentages and plotted against relative sunspot number. As can be seen, the interference is relatively insensitive

to sunspot number in the lower ranges, oscillating about an approximately 40-percent average. For sunspot numbers above 160, when solar flares and radio emissions are much more likely to occur, the occurrence of interference does begin to increase, reaching 60-percent average for sunspot numbers of the order of 200.

Solar Flares and Sudden Ionospheric Disturbances

Definition

Solar-flare data as listed in "Solar-Geophysical Data" include the start and stop times observed by particular observatories, also some indication of a flare's importance. A dual importance scheme is used, indicating both the flare's size and its brightness. Thus, a flare may be ranked from 0F (small, faint) to 4B (large, brilliant). The sudden ionospheric disturbance listings generally include an indication of the specific known flare with which that particular disturbance is associated.

Findings

The immediate effects of solar flares are line-of-sight phenomena detectable only during daylight hours. Unfortunately the main WEFAX transmissions generally occurred between 0900 and 1200 UT, or between 2300 and 0200 local time at the satellite. Thus, transmissions usually began as late as 1800 local time at the westernmost stations and ended as early as 0700 local time at the easternmost stations, or occurred largely at night. While this drastically reduced the opportunities for noting direct solar interference, the combination of occasional multiple transmission days with the delayed effects of solar flares made it possible to isolate certain specific transmissions where solar interference was definitely a factor.

In five cases it seemed that interference problems could be traced directly to solar-flare activity. Table 1 summarizes these cases, giving the date, time, and importance of the flare, and the percentage of stations reporting interference. These cases will be discussed individually below.

On February 13 several observatories reported a flare of importance 1N (normal brightness) beginning at 2213, 4 minutes before the beginning of the WEFAX transmission and lasting until 2250. Only three

stations reported monitoring this transmission: Guam, Christchurch (New Zealand), and Lake Jackson (Texas). Guam, which was in twilight, reported no interference, while Christchurch and Lake Jackson both reported static and atmospherics. Lake Jackson, in particular, reported an end of interference at 2250.

On February 23 a large bright flare of importance 3B began at 0831 and ended at 0848. A WEFAX transmission began at 0830 and ended at 0930. All stations still within daylight

Table 1

Solar Flare Interference.

Date	Start	Stop	Importance	Percent of Stations Reporting Interference
Feb. 13	2213	2250	1N	67
Feb. 23	0831	0848	3B	67
Apr. 1	0151	0213	1B	60
May 26	0900	0945	1B	68
July 4	0940	1105	1B	75

at the time of the flare reported reception difficulties during the early part of the transmission.

On April 1 a solar flare of importance 1B was in progress at the beginning of the WEFAX transmission at 0202, and lasted until 0213. Of the five stations reporting, those two reporting no interference were both in darkness at the time.

During the latter part of May 1967, considerable solar activity with numerous flares occurred by day, so that while a flare of importance 1B did occur during the 0900-1000 WEFAX transmission on the 26th, it was impossible to distinguish its effects from those of earlier flares. Geomagnetic activity levels at some stations on this date were among the highest ever recorded. Toronto reported static bursts, possibly caused by direct solar radio emission and radio fadeout. A few days later, Aberdeen (South Dakota) reported auroral activity and continuing interference. This was during one of the special-data collection periods; 68 percent of the correspondence from 23 stations reported interference.

Again, during late June and early July, there was more than average solar flare activity, although the geomagnetic activity index remained low. A solar flare of importance 1B did occur during the 1030-1130 transmission period, and six of the eight reporting stations noted interference even though most were in darkness. This case would have been dropped but for the fact that some of the stations that almost never reported interference suddenly did so, indicating wide-spread interference of some kind.

Solar Radio Emission

Definition

As was stated under "Background Information," there were several types of solar radio emission. We are concerned here with those relatively short bursts not associated with any known solar flare. Presumably, the more spectacular noise bursts related to solar flare were automatically included in the previous sections. "Solar-Geophysical Data" lists outstanding occurrences of solar radio emission, giving date, time, duration, type, strength, and frequency of observing stations. These data are compiled from seven stations operating at 14 different frequencies from 107 MHz at Haleakala, Hawaii, to 10,750 MHz at Pennsylvania State University.

Findings

During the 8 months of this study, solar radio emission was noted on 37 occasions during WEFAX transmissions. Many of these occurred during local darkness at the receiving stations or were associated with particular flares. In only seven of the remaining cases did solar radio noise seem to have been the possible source of some of the interference problems reported. The failure of the stations in general to note the exact time of the noise bursts precluded our drawing any final conclusions regarding the significance of the static reported in these cases. It should be noted, though, that reports of static bursts were much more prevalent during these periods than at other times.

Geomagnetic Activity and Magnetic Storms

Definition

Geomagnetic activity is measured by means of the "K-indices." These effectively measure for each observatory the range of the most disturbed element for each 3-hour period of the day, after removing the effects of the diurnal variation. The indices range from 0 (no departure from the quiet-day variation) to 9 (recorded only during the greatest magnetic storms) in steps of $1/3$ of a unit. These data are gathered from 12 observatories between geomagnetic latitudes 47 and 63 degrees. Magnetic storms are not examined separately, but it should be noted that they are ranked as moderate if the K index reaches 5, moderately severe if it reaches 6 or 7, and severe if it reaches 8 or 9.

Findings

As mentioned previously, the interference data were converted into a form indicating the percentage of stations reporting interference to facilitate correlation with the geomagnetic activity indices. Except for the collections of special data, the day-to-day correlations were difficult to evaluate, largely owing to the small number of individual reports making up a given percentage. Within the special data collection periods, however, there was generally excellent correlation between the occurrence of interference and geomagnetic activity. Figure 2 shows one such period from January 3 through 12, 1967. All transmissions during this period occurred between 0900 and

1100. The geomagnetic activity indices used were for the fourth daily 3-hour range, or from 0900 to 1200. As can be seen, the correlation is remarkably good.

Figure 3 shows interference percentages versus geomagnetic activity for all cases. The

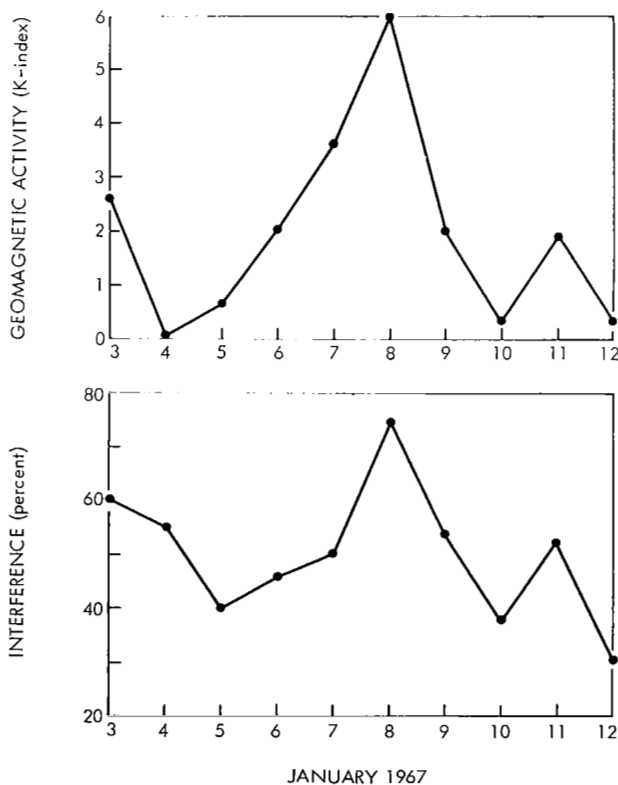


Figure 2—Correlation of interference with geomagnetic activity.

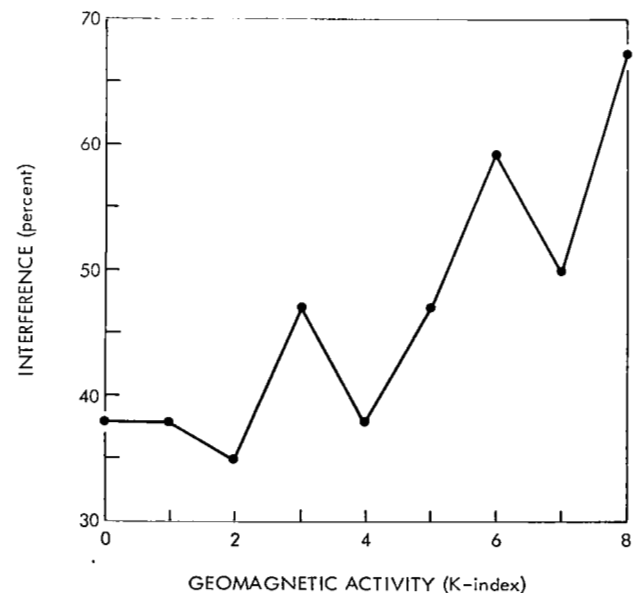


Figure 3—Interference vs geomagnetic activity.

characteristic of the curve is not smooth, owing to the paucity of data points. The trend of the curve is evidently an increasing one.

SUMMARY

There is no question but that solar phenomena did in one way or the other affect the quality of the 135.6 MHz transmissions. The actual sunspot number played a part only insofar as a higher number implies a more active sun, with increased chances of solar flares or radio emission. Solar radio emission apart from that associated with specific flares was relatively ineffective, although there is evidence that a few of these short intense bursts resulted in degraded reception at some stations. The immediate and delayed effects of solar flares were the most directly correlated with interference problems. Periods of high solar-flare activity were directly reflected in increased reception problems, particularly during the very active period in late May. Correlation of geomagnetic activity with interference could be best seen during the collection of special data, when enough data were available to yield statistically significant percentages.

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